The SA-75 Dvina, S-75 Volkhov



In 1953 following the installation of S-25 Berkut system around Moscow the Council of Ministers of the Soviet Union decided about the further development of the air defense of the Soviet Union. Because of the intolerable cost of S-25 Berkut (about 13 billion Rubles) they decided to develop two new SAM systems. Leningrad – the second most important Soviet city – was planned to protected by the multi target channel "Dal" system (SA-5 Griffon), while the rest of smaller, but still enough important cities got the S-75 system (planned cost was about 11 million Rubles/site).

The bureau OKB-301 (leaded by Lavochkin) was appointed to design the fixed multichannel Dal system while the (the assumed) tougher task of designing a cheap towed SAM system was given to Raspeltin's (above right) KB-1 bureau, the successful designer of the S-25 Berkut. According to specification the new system had to use 6 cm wavelength microwave technology with 29 km maximal engagement range up to 20 km altitude.

(The Dal system never entered into service because of the technical difficulties of the development and its cost. The system reached a relatively high level of mechanical completion, the concrete buildings; many main items were manufactured. Regardless of these achievements the project eventually was cancelled, see later more about the Dal in the chapter of S-200 SAM family.)

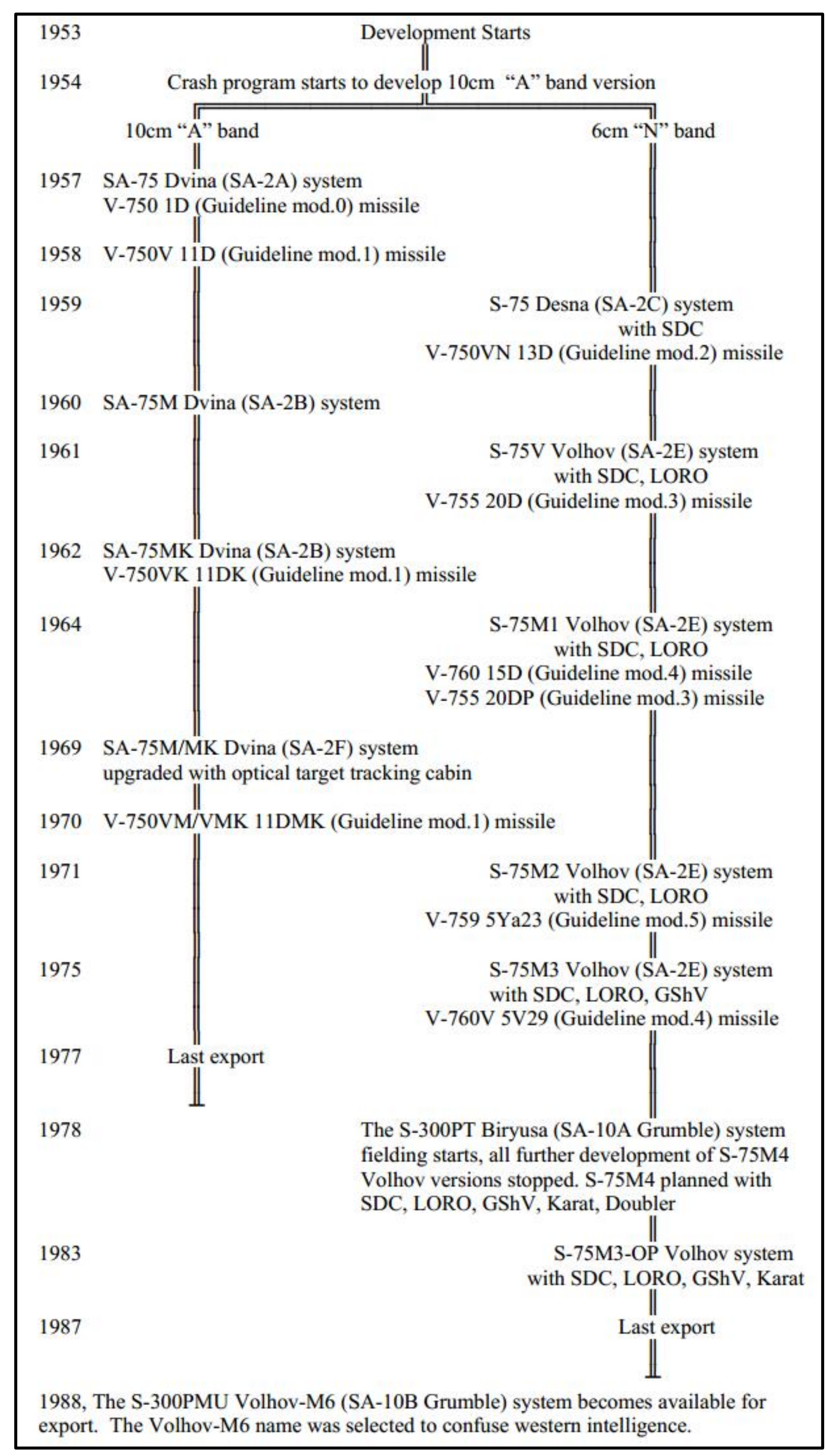
When became evident the development of 6 cm wavelength microwave electronic parts could not be finished until the original deadline a backup/ parallel development started using 10 cm wavelength. This was easier and quicker because some parts of the S-25 could be used as base which also was designed 10 cm wavelength microwave technology. The results of this decision leaded to two different branches of the "75 design". The USSR, WPACT and 3rd world countries used both branches and were in service in parallel for decades. The SA-75 Dvina used 10 cm wavelength while the another branch, the S-75 Volkhov used 6 cm wavelength microwave electronics.

The SA-75/S-75M sub variants were the most widely used (we can say iconic) SAM systems of the Cold War. Besides the USSR and WPACT countries literally all countries in good relationship with USSR used and most of them kept in services for decades. (The list of exported SA-2 and other PVO SAM types are in the attachment.) The SA-75/S-75 variants in the USSR and WPACT were different from what the countries of the 3rd world could get.

The fire control radars of the SA-75 and S-75 used the American Lewis scanner design which never was used in the USA for SAM systems.

The SA-75 and S-25 Berkut used the 10 cm wavelength technology because during the World War II the Soviet Union acquired SCR-584 radars which used the same wavelength. Based on the acquired hardware and knowledge started the development of the Soviet radars. The SA-75 partially used the technology which was developed for the Berkut.

The Soviet copy of the SCR-584 was the SON-9 radar which was widely used even in the '80s they were in the inventory of S-60 anti-aircraft gun regiments/brigades in WPACT and 3rd world countries either.



Above is the evolution tree of the SA-75 and S-75 family.

The main elements of the Dvina and Volhkov changed during their service because of the later upgrades. The changes mostly had impact on the appearance of the fire control radar, the quantity of vans/cabin as well as on the missiles. About a dozen of different sub variants of the missiles developed during the service life of the S-75 family. The main parameters of the different variants and missile are in the chart below:

SAM system type	Cabin types	Missile	Missile range	Missile altitude	Target speed
			km	km	km/h (m/s)
SA-75 Dvina (SA-2A)	PA– fire control radar U – fire control cabin I – indicator cabin K3 – instrument cabin K6 – power distributor cabin	V-750 1D V-750V 11D	5-30 5-34	3-20 3-27	1500/420 1500/420
SA-75M Dvina SA-75MK Dvina (SA-2B)	PA– fire control radar UA – fire control cabin AA – instrument cabin	V-750V 11D V-750VK 11DK	5-34	3-27	1900/520
S-75 Desna (SA-2C)	P– fire control radar U – fire control cabin A – instrument cabin	V-750VN V-755 20D	5-34 7-43	0,5-24 0,3-30	1900/520
S-75V Volkhov S-75M1 Volkhov S-75M2 Volkhov S-75M3 Volkhov (SA-2E)	PV– fire control radar UV – fire control cabin AV – instrument cabin	V-755 20D **V-760 15D** V-755U 20DSU[A] V-759 5Ya23[B] **V-760V 5V29[B]**	7-43 **7-43** 7-43/56* 7-43/56* **7-43**	0,3-30 **?-30** 0,1-30 0,1-30 **0,1-30**	2300/640 **3600/1000** 3600/1000 3600/1000 **3600/1000**
S-75M Dvina (SA-2F)	same as S-75M (SA-2B)	V-750VM 11DM V-750VMK 11DMK + all previous missile variants	5-34	0,1-30	3600/1000

In the chart above for each SAM type the best available missiles are displayed. The other subtype of the missiles with smaller differences can be found in the SAMsim manual, see in the attachments. The target speed and range values are valid in case of non-maneuvering target without ECM protection with 0 km offset distance.

*** Only against subsonic targets in passive terminal phase (after burnout of the engine), otherwise 43 km. The range values are slant range is all cases.***

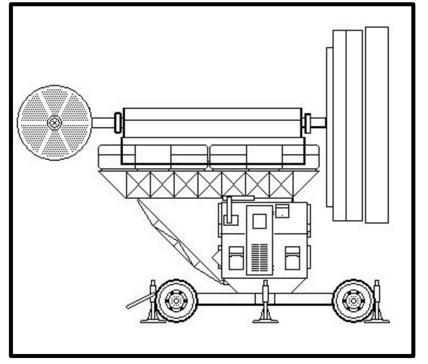
A – 6.5G overload capability

B – 9.0 G overload capability

Missiles types are marked with red were equipped with 15 kt nuclear warhead.

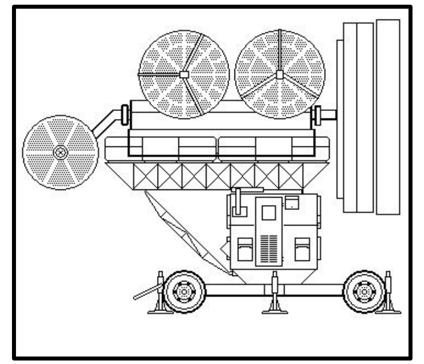
The appearance of the different fire control radars are on the following page. Comparing to the 1st generation Dvina the Volkhov got to extra parabolic antennas. Besides this the main difference was the optical target tracking system which was also different from Dvina. A more primitive method was available for upgraded Dvina, these variant was easily recognizable because of the “doghouse” on the fire control radar (marked with red arrow on the next page), while the Volkhov got the more advanced elector-optical Karat (TV) system (marked with green arrow). These main changes supported the new capabilities besides the different microwave electronics and many more upgrades on the missiles.

The main capability limitation remained during the whole career of the S-75 family, it had only a single target channel, only one target could be engaged by a single battery but was possible to guide up 3 missiles against a single target. At first sight maybe has no sense launching more than one missile against a single target but later will be explained (at aircraft flight performance) the reason behind this feature.



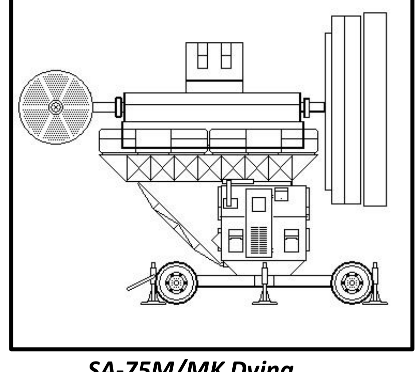
SA-75 Dvina, SA-75M/MK Dvina, Sz-75 Desna

(SA-2A, SA-2B, SA-2C)



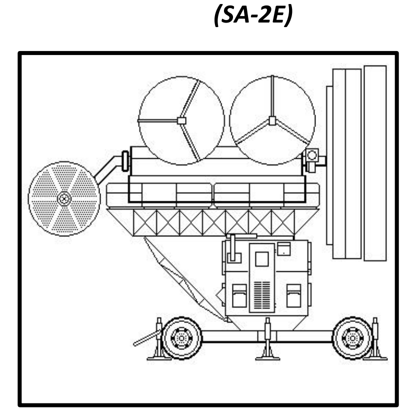
S-75V/M1/M2 Volkhov

(SA-2E)



SA-75M/MK Dvina

(SA-2F)



S-75M3-OP Volkhov

(SA-2E)

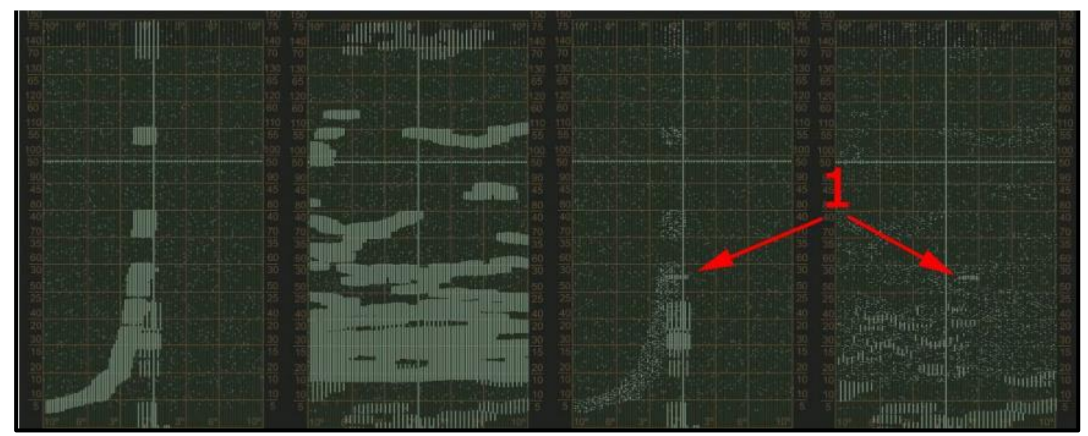
Without listing all upgrades the most important changes during the Dvina and Volkhov career are listed below:

When the CIA started regular recon (spying) overflights above the Soviet Union was not available effective air defense against the U-2. The U-2 could fly just some thousand meters above the maximal engagement altitude of the V-750 1D missile, was not possible intercept the U-2 even with supersonic fighters either. (The maximal service ceiling of fighters were much lower, even with air to air missiles was impossible shot down the U-2.) By increasing the thrust of the second stage of the missile was created the new V750V 11D (Guideline mod.1) variant which could reach 27 km altitude. The development of the missile was finished in 1958. Thanks to the new missile was possible shot down the U-2 which eventually happened in 1st of May 1960 by an S-75 Desna (SA-2C) using V-750VN 13D missile (Guideline mod.2). Also for the Desna variant was available first the SDC mode which made possible to intercept targets in ground clutter.

If the target is flying at very low altitude the ground clutter can make the target acquisition difficult. The SDC makes possible differentiate the ground and target by their radial speed. It has to be noted by the usage of SDC low radial speed (hovering or parallel flying) targets can completely disappear from the indicator.

During the Vietnam War the leadership of the USSR did not authorize the export of the more advanced S-75M Volkhov (SA-2E) and the S-125M Neva (SA-3B) for Vietnam. Because of the mined naval ports of North Vietnam the only way transporting heavy equipment to North Vietnam was possible on railway through China. The leadership did not want to take risk that new and best SAM systems “by accident” fall into hands of China. Because of this fear an upgrade program was initiated and was exported from 1969. Beside the electronic warfare upgrades the package included the optical target tracking capability, after the changes appeared the “doghouse” on the fire control radar of the Dvina. Later all exported “three van”

SA-75M Dvina (SA-2B) got the upgrade therefore became capable to use the V-750VM/VMK 11DM/DMK (Guideline mod.1) missiles.

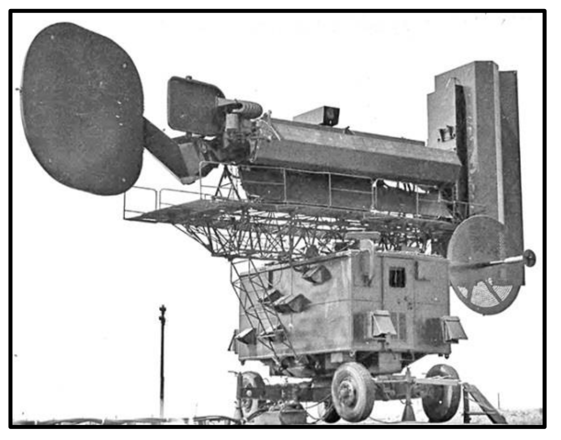


On left side are indicators (elevation and azimuth) the ground clutter reflections. On right side are the indicators in case SDC is applied. The ground clutter does not disappear completely but targets can be tracked at least manually in case auto target tracking is not possible, see later. (The images are made with SAM simulator software.)

In 1964 entered into service the S-75M1 Volkhov which was able to use against large bomber flights missiles with nuclear warhead thanks to the new V-760 15D (Guideline mod.4) missile along the RD-75 Amazonka range finding radar. In case of jamming the RD-75 provided an extra tracking option it used different wavelength from the other radars, the Amazonka (on the image right) ensured the detonation of the nuclear warhead in the right moment. (The American Nike Hercules used the same approach.)



In 1971 arrived the S-75M2 variant which got the new V-759 5Ya23 missile with increased maneuvering capability. Comparing to previous 6.5G maximal overload the new missile was capable to reach 9G below 10 km.



From 1975 arrived to troops the S-75M3 which got the anti-jamming circuits (GSV) against angle deception jamming – the GSV and SDC could not be used in the same time – and as usual got a new missile the V-760 5V29 (Guideline mod.4) with nuclear warhead which based on the earlier V-759 variant. Of course the system was backward compatible the earlier 20D/15D/5Ya23 missiles also could be used.

In November of 1978 the testing of new S-75M4 was in progress it introduced the 9Sh33A "Karat" target tracking TV camera, a new narrow beam antenna system, capable of tracking low altitude targets with small radar cross section and the "Doubler"[1] equipment to confuse anti-radiation missiles with a false emitter.

In parallel with developing the S-75M4 in 1978 deploying the first S-300PT Biryusa (SA-10A Grumble) system started around Moscow. Because the successful deployment of the S-300PT all further development work on the S-75M4 was immediately stopped, the project was canceled but the developed new items

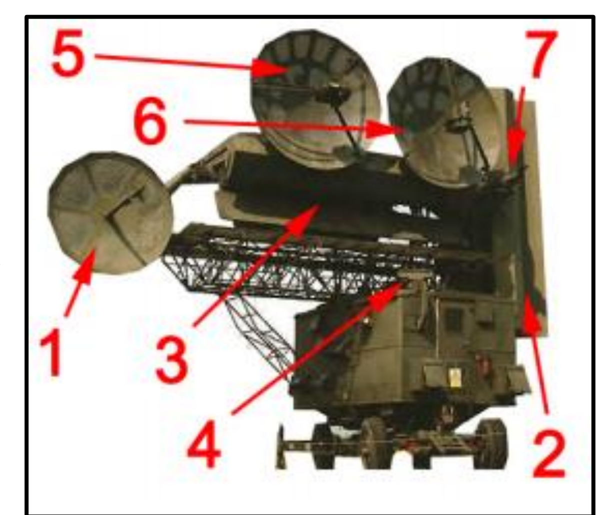
[1] *Later none of Volkhov ever got this device not even in the Soviet Union.*

were made available as an upgrade package to earlier S-75 variants. The S-75M5 project also was cancelled it that time M5 was only a paper design which could use the V-500RD missile and the low level search radar (NVO / Clam Shell) of the new S-300 system.[2]

The S-75M3-OP (SA-2E) Volkhov appeared first in 1983. It got the successfully tested 9S33A Karat electro-optical target tracking system. During the regular 5 year overhaul/maintenance older versions received the later developed upgrades, therefore in theory all Volkhov variants were at the S-75M3-OP level at late '80s.

Explanation of the capability of the S-75 family is carried out by the most advanced Volkhov variant referring to differences between the Dvina and other older variants. The main parts are the fire control radar is the followings:

1. P-16: dm wavelength, missile command transmitter antenna.
2. P-12V: 6 cm wavelength, wide beam, elevation (ε- epsilon) antenna.
3. P11V: 6 cm wavelength, wide beam, azimuth (β- beta) antenna.
4. (Azimuth dummy antenna. The elevation dummy antenna is at the back of the cabin.)
5. P-14V: 6 cm wavelength, narrow beam, elevation (ε- epsilon) antenna.
6. P13V: 6 cm wavelength, wide beam, azimuth (β- beta) antenna.
7. 9Sh33A Karat camera. (optical channel)



From the listed antennas above the '5' and '6' labelled were not available on the fire control radar of Dvina and instead of Karat camera the manned "doghouse" was installed which provided a much more primitive optical target tracking method. The '2' and '3' labelled antennas on Dvina were called PA-12 and PA-11.

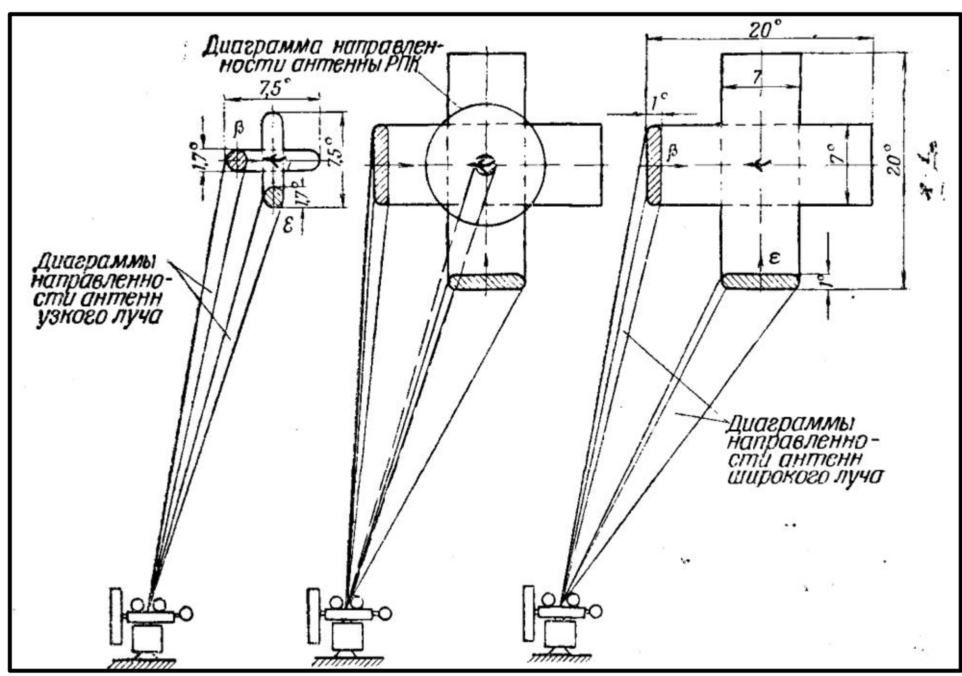
The Volkhov had the following target acquisition and tracking modes:

1. Wide beam mode, see on the drawing on the following page, on right side. In azimuth and elevation P-12V and P11V antennas scan in cross shape with 1x7 and 7x1 degree wide lobes within ± 10 degrees. Target had to be in the overlapped scanned area of the two antennas as well as the missile because of the RCG guidance. (Both the target and missiles had to be tracked this is foundation of RCG.) For the Dvina this was the only available scan and tracking method but the lobes or PA-12 and PA-11 were 2x10 and 10x2 degree wide. (Considering the same emitting power the Volkhov had higher detection range because the same power was emitted to smaller airspace.)

2. Narrow beam mode, see on the drawing on the following page, on left side. Scanning with P-14V and P13V antennas with 1.7x1.7 degree wide lobes within ± 3.75 degrees. This mode was available only for Volkhov branch in the S-75 family because it used the two parabolic antennas. Using the narrow beams with the same power resulted 40% higher detection range comparing to wide beam mode.

[2] *See in chapter about S-300 family.*

3. LORO (lobe on receive only), see on the drawing on the following page in the middle. The P-14V and P13V antennas illuminate the target but P-12V and P11V receive the reflected waves from the target and from the radio beacon of the missiles. The P-16 RC antenna sends guidance signals to the missiles with a 20x20 degree wide lobe. The missiles have to be within the overlapped area of scanned area of wide beam antennas (7x7 degrees).



Above are the S-75M target tracking methods/modes, from left to right are the narrow beam, LORO , wide beam mode. [3]

The S-75 family uses radio command guidance (RCG) method. They system tracks both the missiles and target which mean a very strong restriction considering the concept of the system. In wide beam mode the system can provide both the azimuth and elevation data from a 7x7 degree (10x10 degree for Dvina). In case only one of the beam scanned the target only on one of the indicators was visible the target.

Because of this antenna configuration and lobe parameters in all modes – even in LORO – target and missiles have to be in the overlapping scan zone of wide beam antennas. This is why did not have anti-ballistic missile capability the Volhkov because in most of cases missile had to follow such trajectory (guidance leading) which would make impossible to track both the target and missile with the P-12V and P11V antennas. Of course the antenna system of the fire control radar could be turned left/right and tilted up/down for target tracking, but the radar station was not able to fully rotate (what long range EW/target acquisition radars designed to do).

The LORO mode provided the same advantages comparing to wide beam tracking:

- LORO provided higher detection and tracking range comparing wide beam mode. The maximal detection range against MiG-21 size targets increased to 130 km from 70 km. The emitted power was the same as in wide beam mode but with narrower beam the power density was higher. In case of noise jamming the burn through distance was higher when the target appeared in the jamming band on indicators.

[3] *http://historykpvo.narod2.ru/ Зенитный ракетный комплекс С-75М.Учебное пособие – page 18.*

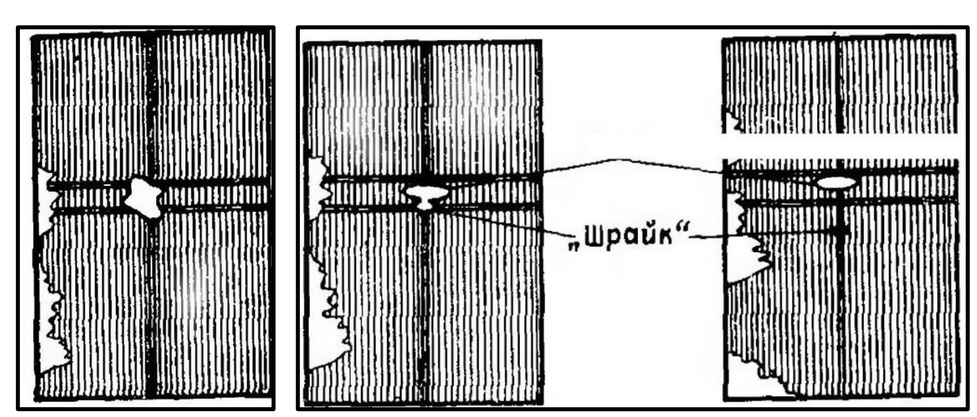
- Because the narrow beam was only 1.7x1.7 degree wide except that tracked aircraft RWR was not able to detect the emission from the fire control radar except airplanes in very tight flying formations. (Assuming 30 km tracking range this means smaller than 500 m distance between aircraft next to each other.)

- The AGM-45 Shrike anti-radiation missile was not able to target fie control radars by their emitted side lobes as the later developed AGM-88 HARM. In case Volkhov used LORO it made impossible to aim & attack with AGM-45 from such large airspace as was possible against Dvina which had only wide beam mode. (The AGM-45 platform has to fly inside the lobe) Considering real life situations AGM-45 very likely could be used only from airplanes which were tracked by the fire control radar, it would require very close formation flying and cooperation with SEAD escort and other airplanes to be able to launch AGM-45 from different airplane than the target.

The larger detection range is more important against high speed target such as AGM-28 which can travel with about 700 m/s at 17 km altitude. The maximal engagement distance of the system can be used only in case target tracking is possible at much higher distance than the engagement zone of the Volkhov which can be seen later on the engagement envelope/zone diagrams. The maximal engagement distance shows the maximal distance from the SAM site where the missile intercepts the target which is different from launch distance. Later we can see the maximal engagement distance against such high speed target is 43 km, the missile reach this point about 50 seconds after the launch. During this time interval the AGM-28 can fly about 35 km.

Even the missile does not fly directly towards to the SAM site the first detection and tracking has to be much higher than 43 km or even the 43+35 km. Even for a well-trained crew about 30-40 seconds is needed from first detection to launch, not mentioning even just spinning up gyros in the missile which required 30 seconds. (Such ready to launch state could be maintained only for 5 minutes.) Considering all of these factors against AGM-28 missile 80-100 km first detection rage was desirable, which was smaller than a MIG-21 which meant smaller RCS. This example helps understand what the point of LORO mode was.

Besides the advantages of LORO mode has some disadvantages. In Vietnam in combat crew could see for a short time when the launched AGM-45 ARMs separated from the tracked target time, two target marks were visible on indicators. In wide beam mode the scanned airspace is larger comparing to LORO mode. AGM-45 could be launched within the emitted lobe but the later developed AGM-88 could use side lobes which made possible the “all aspect” attack. Considering this threat LORO was more dangerous because in case of a larger flight or package with LORO mode only a single target could be tracked but the AGM-88 launch could happen more easily without being detected.



Above is the indicator of a Dvina, the separation of the AGM-45 is visible in case the target was within the scan zone of the SNR-75.

During the Vietnam conflict crew of SAM sites discovered some US fighter planes could detect and identify separately the emitted fire control radar beam and the RCG signals for the missiles with their RWR. When the RCG signal was detected by the RWR the crew of an engaged airplane knew not only about the radar tracking but also was aware of the missile launch. (RCG signals were emitted with 20 degree wide beam.)

The crew of SAMs exploited (in that time) the advanced RWR capability of some US jets. The cheap trick was they turned on the system and emitted RCG signals without launching any missiles. From point of view of US pilots it seemed a missile launch happened they just not have detected the missile visually. Flying even best high performance fighters with lots of bombs and drop tanks made much harder to evade missiles with maneuvering therefore many time pilots jettisoned their weapons because of the warning of RWR to prepare the evasion of launched missiles which never happened. Using this trick many time saved the targets the crew of Dvina even without launching a single missile.

This method was so liked by the Soviets they built this feature into Volhkov variant; the system performed this trick at random automatically without any operator activity in case SNR-75 turned on. In the era of AGM-45 this was nice feature because the SAMs could not be attacked using the side lobes but the AGM-88 from early-mid '80s could use side lodes.

This leaded the situation which was a good idea for deception it became suicidal in the age of AGM-88, literally it made a "HARM magnet" the fire control radar of the Volkhov without giving feedback to crew about this activity and launching a single missile. This automatic function could be bypassed but only for a well-trained crew.

The LORO mode was not good in some other cases for example against low flying targets because of the architecture of the system. (See in the attachments, **SA-2E_English_Advanced-V1 [ENG]** page 15 and 16; pdf) Regardless all of benefits of LORO it was not always a good choice the wide beam mode remained usable and necessary for Volkhov.

There were two different missile trajectory leading settings but after experiences of Vietnam conflict it was added one more. The leading type could be set in-flight or before the launch but the latter was preferable because before 20 seconds of calculated impact even was possible it was not a good choice to change the setting because it lowered the chance of hit. The following settings were available:

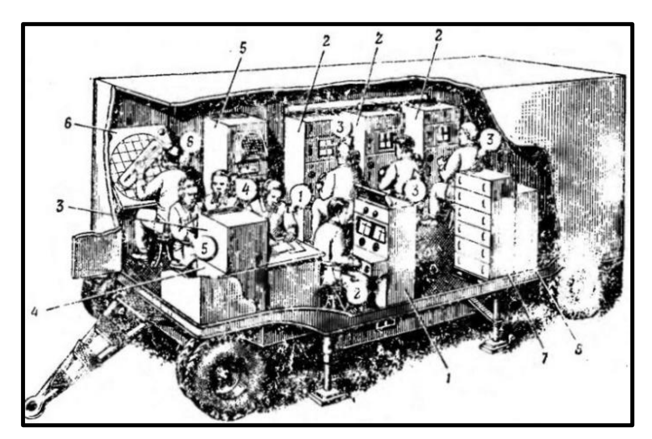
1. Half-lead
2. Three point guidance (T/T)
3. Half-lead elevated by constant (K method)

The first method was used against non-jamming targets using or with manual target tracking in case distance between the target and the radar was available, but automatic target tracking was not possible for example because of angle deception jamming or ground clutter.

The second method was used in case of (noise) jamming when the distance of target was not known. Missile guidance was possible in this case with manual tracking, but against maneuvering targets or in case of overlapping / interfering vertical bars (see in another chapter) the chance of hit was lower because of the weak maneuvering capability of the missile.

The third leading method is the special variant of the first. During Vietnam the US pilots figured out in case of steep diving the calculated intercept point was below the ground level. If the pilots after missile launch made a very quick dive – in case speed and altitude allowed it – the control system of the Dvina simply

guided the missile into the ground because the system had no idea about where the ground level was. The guidance control simply calculated the intercept point by using measured target data regardless it was below ground level. Using this leading setting in elevation the guidance is corrected with a K constant parameter to avoid the ground collision issue.



On left is the UV fire control cabin. It was not so comfortable or ergonomically well-designed. [4]

The point of a SAM system is automatic target tracking and automatic missile guidance; the system accuracy has to be independent from manual skills of the crew. In case automatic tracking is not possible for example because of jamming by the data of indicators crew in the UV cabin using small handwheels can set elevation and azimuth for missile guidance, one small handwheel is available for each axis.



The three point guidance can be used in case the information (jamming bars) appearing on indicator screens. Optical target tracking is also possible to get azimuth and elevation data about the target for guidance input for three point method. (Half- leading is not possible because target speed is not known.)

For optical tracking the Volkhov had the black and white “Karat” TV system, for the Dvina only a much more primitive mode was available. Above the PA-11 antenna in the “doghouse” two operators with binoculars tracked the target manually using handwheels, one for each axis. The handwheels were coupled electrically with the small handwheels of the UA cabin. In case the crew of “doghouse” used the handwheels the system accepted as input as the operators would use the small handwheels in the cabin when jamming bars were on the indicator screens.

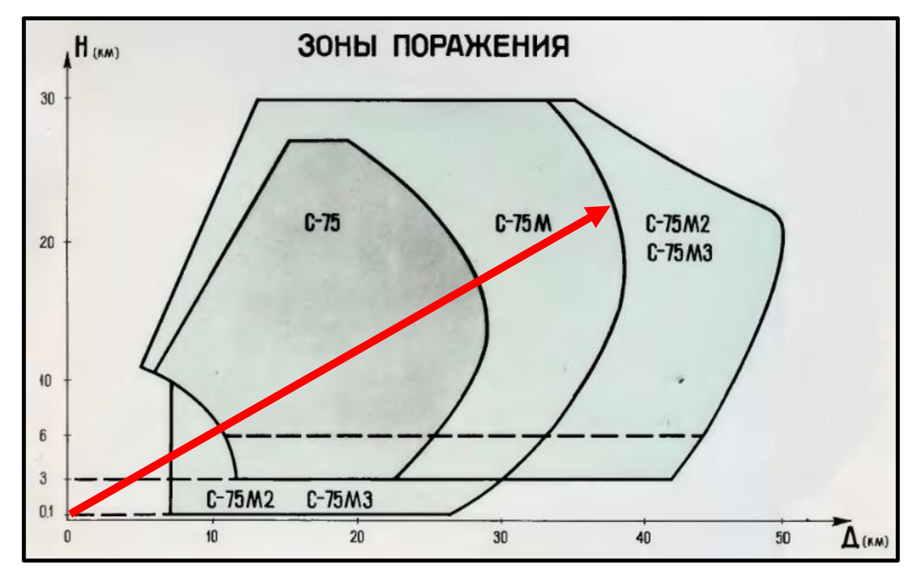




Above is the interior of the “doghouse” workstation on the radar station of the Dvina.

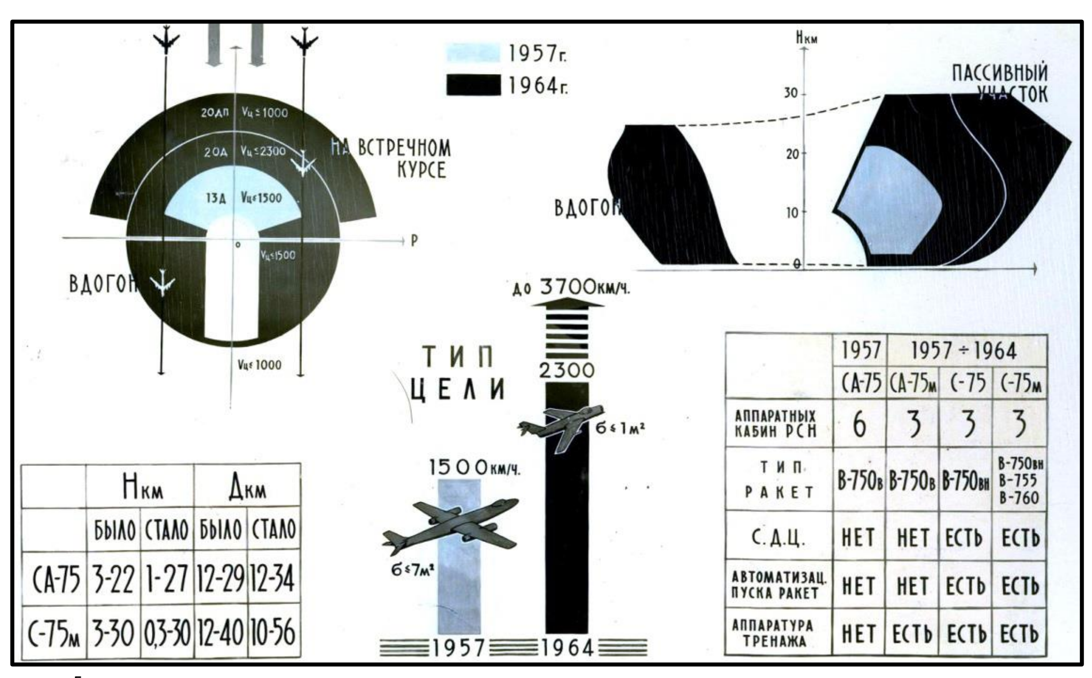
[4] *http://historykpvo.narod2.ru/ Зенитный ракетный комплекс С-75М.Учебное пособие, page 11.*

After knowing the guidance and leading methods and their limitations it is time to speak about engagement zone/envelope of the system. Below is a simplified diagram about engagement zone of different S-75 variants.



Above is the engagement zone of different S-75 variants against non-maneuvering targets, without electronic jamming up to 300 m/s target speed. (Target offset distance is 0 km)

On the diagram above the 43 km slant range is marked with red arrow. Above 43 km target speed can be only subsonic the engine of the missile is burnt out at this region the missile strongly deaccelerates the turning capability is reduced because the missile loses speed very quickly. This simplified diagram shows only the fraction of the engagement zone of the S-75 Volkhov variant, but at least against the scale of engagement zone against most common target (subsonic airplanes) can be judged.

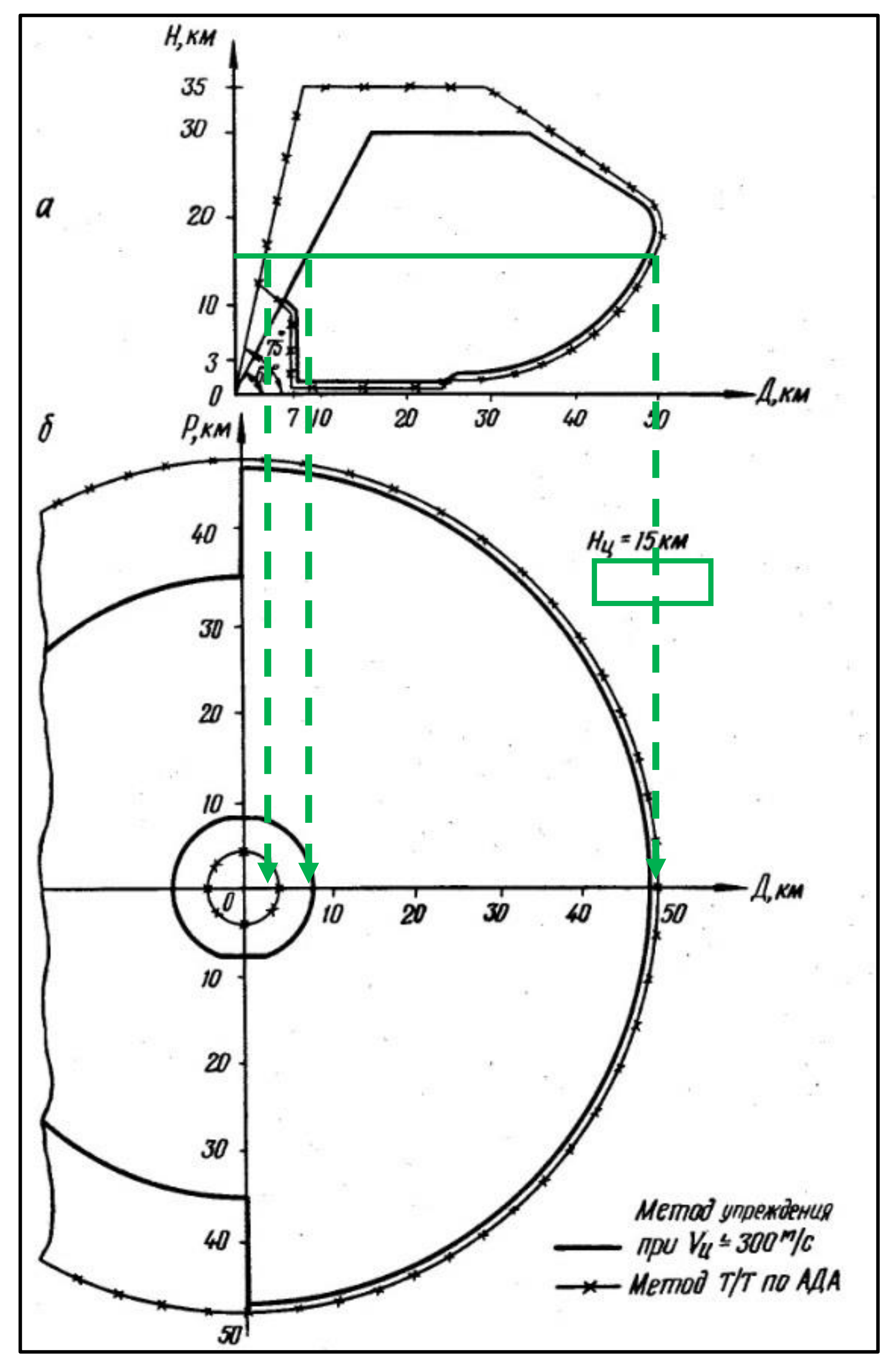


	Нкм		Дкм	
	БЫЛО	СТАЛО	БЫЛО	СТАЛО
СА-75	3-22	1-27	12-29	12-34
С-75м	3-30	0,3-30	12-40	10-56

	1957	1957 ÷ 1964		
	СА-75	СА-75м	С-75	С-75м
АППАРАТНЫХ КАБИН РСН	6	3	3	3
ТИП РАКЕТ	В-750в	В-750в	В-750вн	В-750вн В-755 В-760
С.Д.Ц.	НЕТ	НЕТ	ЕСТЬ	ЕСТЬ
АВТОМАТИЗАЦ. ПУСКА РАКЕТ	НЕТ	НЕТ	ЕСТЬ	ЕСТЬ
АППАРАТУРА ТРЕНАЖА	НЕТ	ЕСТЬ	ЕСТЬ	ЕСТЬ

On the image[5] above are the main differences between Dvina and Volkhov. Target speed, altitude and offset distance are different as well as the minimal RCS of target which can be tracked. Dvina could track targets down to 6-7 m^2; Volkhov could track 1 m^2 RCS size targets.

[5] http://historykpvo.narod2.ru/
Альбом фотоиллюстраций по расширению ТТХ и боевых возможностей комплексов С-25 и С-75, page 4.



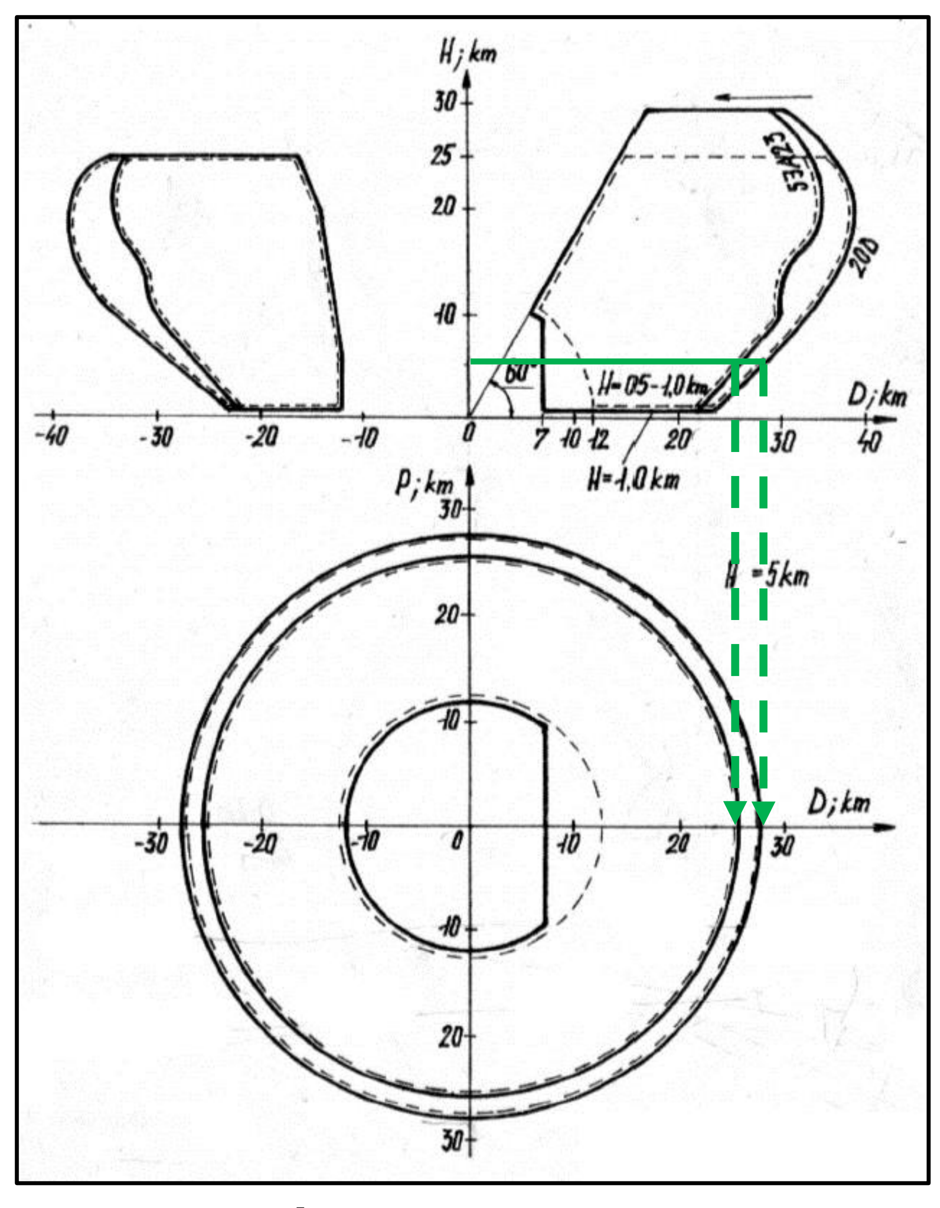
The engagement zone of S-75 family is even more restricted in many cases, especially against high speed and jamming targets. The common representation of a simple circle around the SAM battery is false, on the diagrams below are shown these limitations, above[6] is the engagement one of S-75M3 against non-maneuvering target up to 300 m/s without electronic jamming.

[6] *http://historykpvo.narod2.ru/ - правила стрельбы комплекса С-75М Волга ПС 75 - 45.oldal*

The top view of the engagement zone shows the section view at 15 km altitude to show the maximal engagement distance. (Tactical fighters and bombers never fly higher altitude; fighters and strike fighters flew rather below 10 km.)

The maximal offset distance against incoming targets is 45 km but against receding targets is only 35 km. The maximal engagement distance is 47 km (at 15 km altitude), the minimal distance is 7 km, the minimal engagement altitude is 0.1 km, maximal altitude is 30 km (in case smaller horizontal range than 35 km.) The ranges in every cases are slant range not horizontal (projected) range.

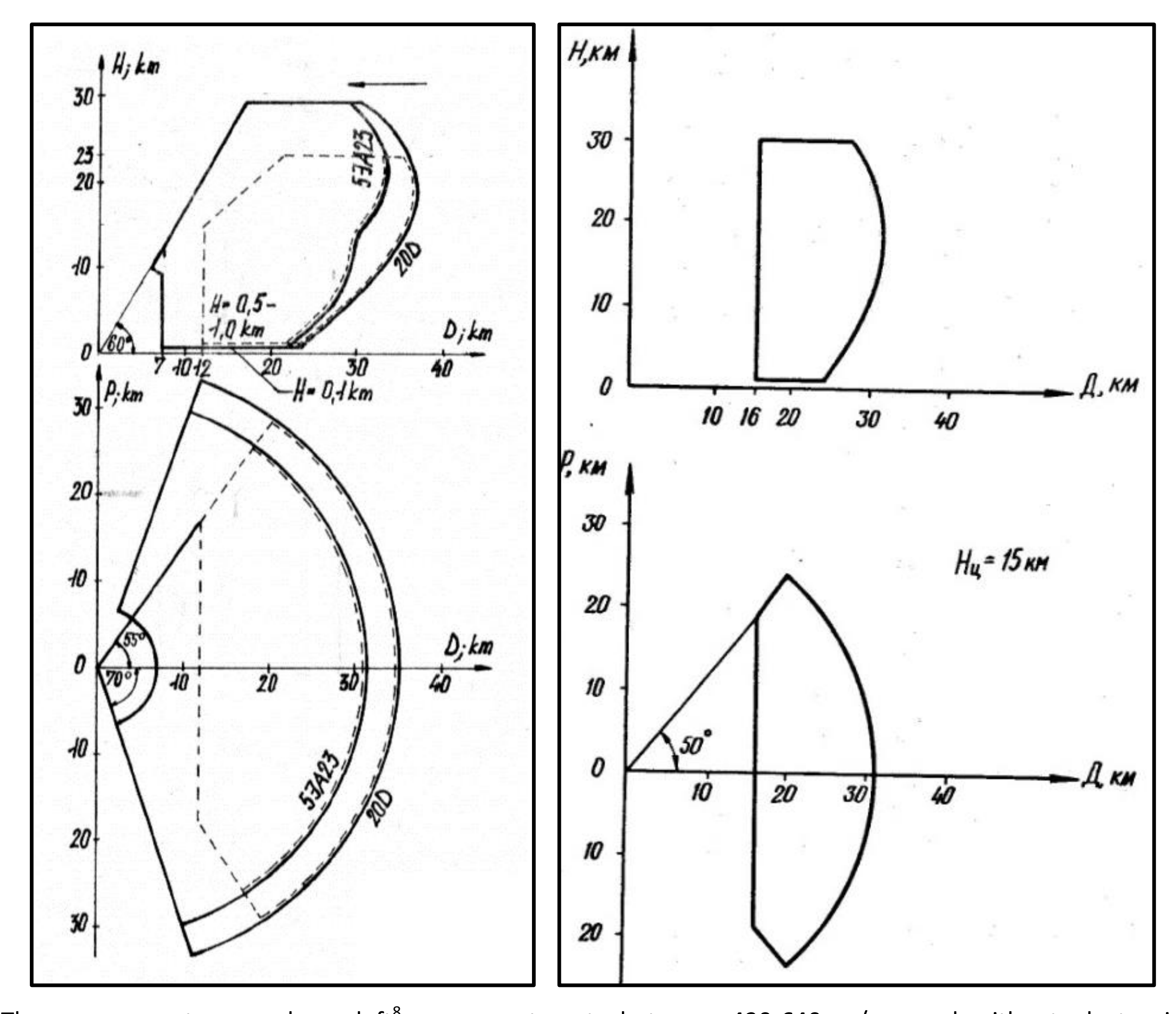
The engagement zone is marked with stars on lines shows the engagement zone using three point guidance mode against slow balloons. The maximal engagement altitude is higher because target speed is low, missile does not have to make hard turns. (USA tried to use spy balloons against the USSR, the operation was unsuccessful.) This zone was meaningless it does not show the limitations against most typical airplane targets.



The engagement zone above concerns[7] targets up to 420 m/s (Mach 1.5) without electronic jamming, the zone against incoming and receding targets are not the same. The top view shows the engagement zone at

[7] http://historykpvo.narod2.ru/ - *правила стрельбы комплекса С-75М Волга ПС 75, page 42.*

5 km altitude. The maximal engagement distance is smaller than against subsonic targets, we can say as the target speed increases the maximal engagement distance and offset distance decrease.



The engagement zone above left[8] concerns targets between 420-640 m/s speed without electronic jamming. We can see the strong changes in offset distance limitation; the engagement zone is not circular anymore. On the right above is the engagement zone against[9] targets between 640-1000 m/s. (Maximal speed of AGM-28 is about 700 m/s at 17 km altitude) The maximal engagement distance is barley higher than 30 km, the minimal engagement distance is 16 km comparing to the 7 km distance against subsonic targets. The offset distance is very limited comparing to all other previous cases (against slower targets), only 18-23 km.

We can see how strong the speed of target on the engagement zone. Against subsonic targets the zone is almost completely all-round and the maximal engagement range and offset distance are almost the same while against high speed targets (above M2.0) only a small arc is covered by a single S-75M3 Volhkov battery. If targets are intercontinental bombers with freefall nuclear bombs Volkhov batteries with 30 km distance from each other have quite large overlapping engagement zones while if targets are AGM-28 missiles can bypass a SAM ring or SAM defensive line which consist only S-75M Volkhov.

[8] http://historykpvo.narod2.ru/ - *правила стрельбы комплекса С-75М Волга ПС 75 – page 43.*
[9] http://historykpvo.narod2.ru/ - *правила стрельбы комплекса С-75М Волга ПС 75, page 44.*

All diagrams above concern non-maneuvering, non-jamming targets in case of 3 launched missiles considering 99% kill probability. Outside the engagement zones above is possible to achieve a hit but the chance of the hit is considerably lower.

Because the diagram above concern only non-maneuvering targets it has to be underline one of the key limitations of SAM system the kinematics of missile, the maneuvering capability of the missiles. The SA-75/S-75 systems were designed homeland air defense basically against intercontinental bombers which are not famous about their aerobatic capability. Regardless of the basis of design in combat except Operation Linebacker II never was used against intercontinental bombers only against tactical (strike) fighters and attack airplanes, where the limits of Diva and Volkhov systems soon became obvious.

On the diagram below [10] are the available G values of V-755 20D missile in the engagement zone. Three regions of the diagram are important, against tactical fighters up to 8-10 m altitude, against strategic bombers the 10-17 km depending on target speed (B-47/52 were subsonic, B-58 could fly at 17 km with M2.0 as well as the AGM-28) and finally the 20-26 km altitude considering U-2 and SR-71. The maximal G value limits the turning capability of the missile, against tactical fighters is only 6-7G, at very high altitude only 4G turns are possible. In short; the diagrams previously above showed the kinematic range of the missile but does not tell anything about what can do the system against maneuvering targets the diagram below helps to understand this by showing the maximal available G turn capability of the missile V-755. The V-759 5Ya23 could perform 9G turn where the V-755 only 6-7G.

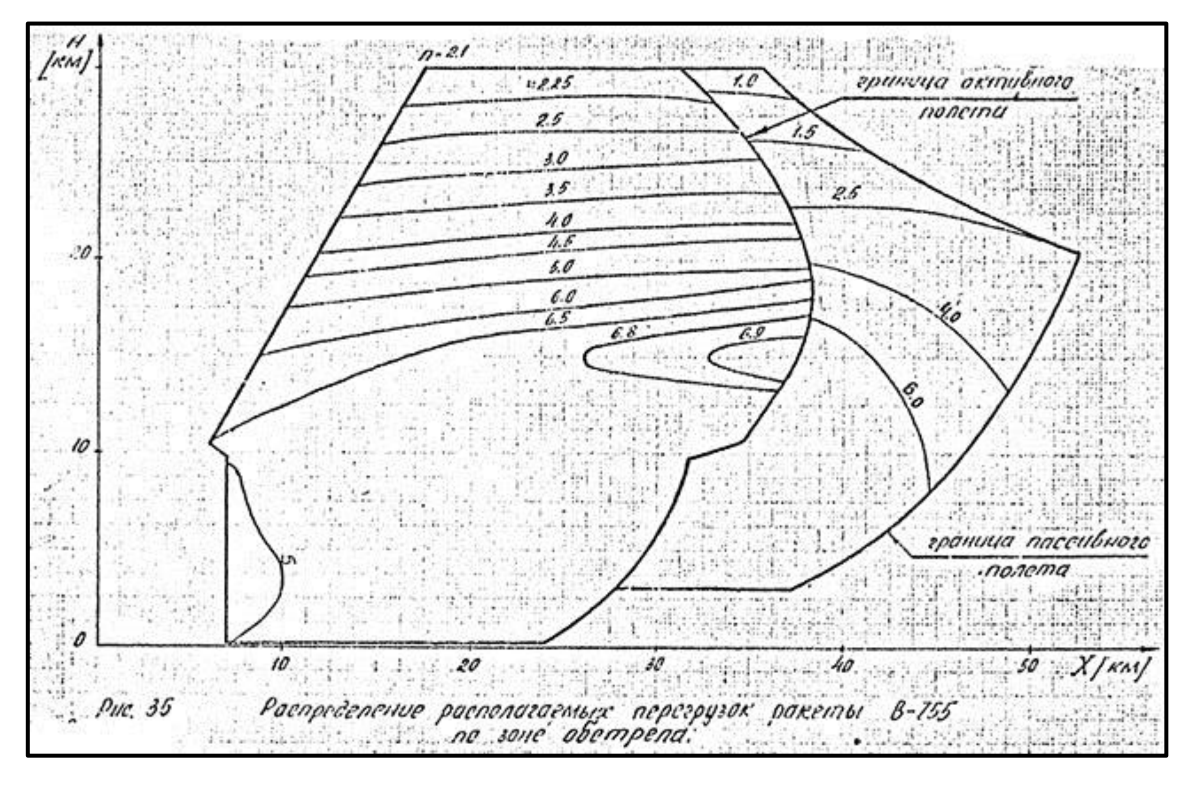


Рис. 35 Распределение располагаемых перегрузок ракеты В-755 по зоне обстрела.

In case of non-jamming target missile used half-lead approach but if target used noise jamming three point guidance method was needed which forced harder turn the missile in terminal phase comparing to half-lead method. If the available G is smaller what the turn demands the missile cannot hit the target. This is why was not successful against the SR-71 the SA-75 Dvina because the jamming SR-71 was simply too fast and flew at very high the 4G turn limitation of the missile simply made impossible the hit. Many times were launched missile on SR-71s without success.

[10] *http://historykpvo.narod2.ru/*
Отчет об испытаниях ЗРК С-75М - 3-я глава Характеристики ракет В-755 и В-760, page 31.

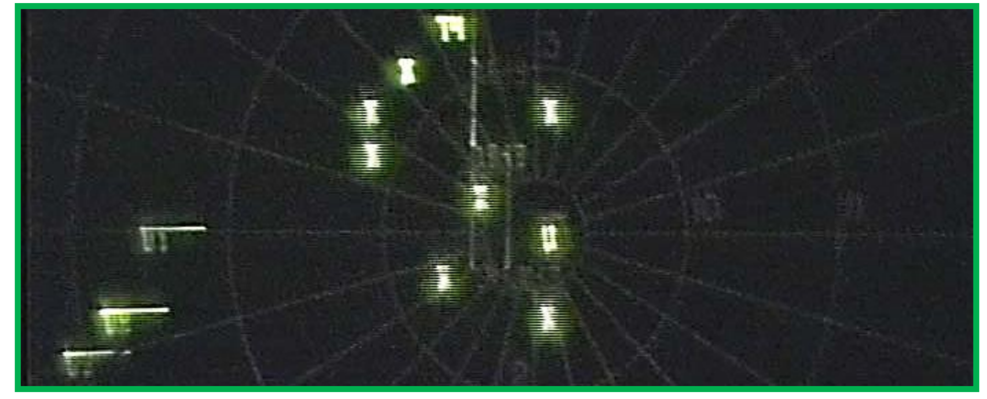
Tactical fighters even without jamming can make so hard turns which makes the hit impossible, the jamming just support the more easier evasion by turns (dodging) because forces the system to three point guidance method, where smaller G turn is enough defeat the missile.

Some words about the structure of a battery. Considering the scan limitation of fire control radar – lack of rotation capability and 7x7 (Volkhov) or 10x10 (Dvina) degree scanned zone – performing 360 degree search for a good tactical picture is not possible therefore the battery a radar which has dedicated role for long range search / target acquisition.

Every Dvina and Volkhov battery besides the fire control radar had 360 degree rotational scan long range search / target acquisition radar (sometimes is called early warning or EW), Dvina had the P-12 type radar the Volkhov had the upgraded P-18 radar.[11] These radars scan all-round in 360 degree the airspace and displayed targets of round shaped indicators (PPI scope).[12] Between two scans the target markings glowed on the scope which make possible to use the manual plotting table target tracking. In case of availability automatized command post the system forwarded electronically to the plot table (indicator) the target data and automatically displayed targets, otherwise plotting crew registered and updated contacts on glass surface with crayons. The rotation speed of P-18 could be 6 RPM or 10 RPM.



Above is the manual plotting method, target data is forwarded via radio in speech form.



Indicator of the workstation of Vektor automatized command system. X - S-75/125batteries, II - S-300PMU battery, 01..03 – targets, 74 – jamming target

[11] http://www.radartutorial.eu/19.kartei/11.ancient/karte049.en.html
[12] http://www.radartutorial.eu/12.scopes/pic/PPI-400x375px.gif

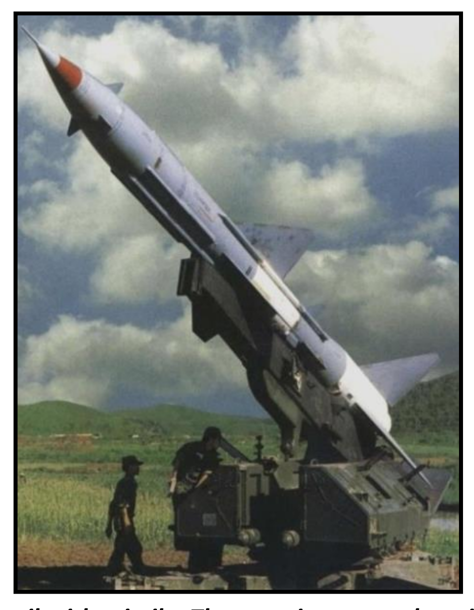
The long range radars used very wide beams therefore measuring target altitude was not possible, also their distance measuring accuracy was in km range moreover at close range they could not measure distance. P-12/P-18 radars were not designed to fire control these limitations and accuracy were enough to provide the necessary situational awareness which target should be engaged by the SAM battery. Comparing to fire control radar the search / target acquisition radar scanned huge airspace with much better refresh time and much longer detection range. The P-12/18 used meter wavelength (P-12/18 –150 MHz, SNR-75 – 3-5 GHz) therefore different jamming devices were needed to jam the fire control and search / target acquisition radars.

The P-12/18 radars used Yagi type antennas. An average Yagi antenna emits 50x90 degree lobe. The P-18 antenna was build up from 8x2 Yagi elements which means in azimuth the lobe arc was 50/8 = 6.2 degrees, in elevation 90/2 = 45 degrees, therefore emitted lobe was 6.2x45 degrees. This is the reason why could scan large airspace the P-18 but was impossible to measure target altitude.




Above left is P-12; above right is P-18 long range EW radar.

Besides the long range search / target acquisition radar the battery could have additional height finder radar but this was not the typical configuration not every operator used it. This radar did not scan in 360 degree it measured the altitude in designated direction if it was necessary. Of course the radar could be turned to left or right but was not able to rotate similar to SNR-75 fire control radar. Volhkov used the PRV-13 (Odd Pair) height finder radar.

Above left is PRV-13; above right is the missile launch rail with missile. The crew is next to the missile provides good reference about the size of the missile.

The battery was operational without the height finder radar because of the azimuth data was provided by P-12/18 radars the fire control radars was enough to set in good direction the SNR-75 then a quick scan in elevation made possible to find the target. At long range the 7x7 degree (10x10 for Dvina) scan zone of fire control radar was enough big to find the target quickly. Most of targets flew below 10 km (except intercontinental bombers) which narrowed down the necessary scanned airspace in elevation.

The missile of Dvina and Volkhov used the same basic conception which was different from the single stage missile of the Berkut. The missiles had two stages, the first stage was solid propelled booster the second traveling stage used liquid fuel. The liquid fuel was the same as was used for S-25 Berkut, a two component very toxic propellant which produced strong smoke trail which made easier the visual detection, especially if the engaged aircraft had RWR support.

After launch the booster stage solid rocket engine ran about 3 seconds[13] and accelerated the missile to about 550 m/s. Following separation of the booster stage was ignited the liquid fuel engine. Until booster stage separation the missile could not performed turns the fins were in fixed positions. The advantage of the liquid propelled rocket engine was the selectable (controlled) thrust which was dependent of the elevation angle of the target. Below 24 degree elevation thrust was about 35 kN for 45 seconds above 24 degree 35 kN for 24 second then 20 kN for 55 seconds. (Most of tactical targets has smaller elevation than 24 degrees.)

The launch weight of different type of missiles was quite similar between 2.15 and 2.4 tons. One battery had six launch rails, on each rail a single missile and six more additional missiles on missile transporter / loader vehicle (PR-11B TZM).

After the 1973 Middle East war the Hungarian Army tripled the number of the available missiles of a battery, from 12 to 36. To store the 24 extra missiles, a new transport vehicle was developed.



Above is the PR-11B TZM missile transporter / loader.

[13] In Soviet sources thrust and burn time data are given to -50C and +50C, above in every other cases the values concern on 20C temperature.

Of course a Dvina or Volkhov battery is more than just the radars, missile launch rails or cabins, a more detailed list of equipment of a single S-75M3 Volkhov battery is listed below.

Main elements of the S-75M3 battery			
Item	**pcs.**	**function and name**	**vehicle**
RSzN-75V3-OP PV cabin (Fan Song)	1	fire control radar	towed
UV cabin	1	fire control cabin	towed
AV cabin	1	instrument control cabin (analog computer)	towed
SM-90	6	launch rail	towed
PR-11BM/D (V-755U 20DSU missile)	6+	missile transporter / loader	towed
AKKORD-75*	1	training emulator	towed
P-12M or P-18	1	long range 360 degree scan EW radar	self-propelled
1L22 Parol 4 or 75E6 Parol 3	1	IFF interrogator unit	KrAZ-255
PRV-13	1	Height finder radar	towed
ESP-90 (3 x 5E93)	1	generator	towed
5Ya61/62/63 Tsikloida	1	radio relay van for automatized command post	towed
5L22	1	Chemical decontamination van	self-propelled
5L22A	1-2	Fuel tank truck (TG-02)	towed
5L62A	1-2	Oxidizer tank truck (AK-27P)	towed

*** Not all batteries had emulator, one regiment or brigade had one and could be assigned to one battery according to training plan.**

****In Hungary none of batteries had height finder radar.**

The method of deployment was dependent by the operator and the tactical situation. The SA-75 and S-75 batteries typically were deployed in static SAM sites. Dvina sites were not hardened sites, only protected excavations / ramparts built around vans, cabins and missile rails. The deployment layout was hexagonal in the middle was deployed the fire control radar, the target acquisition and height finder radars were outside the hexagon and the all-around roads.



An aerial view of Soviet built SA-2B Guideline surface-to-air missiles positioned at a desert location.

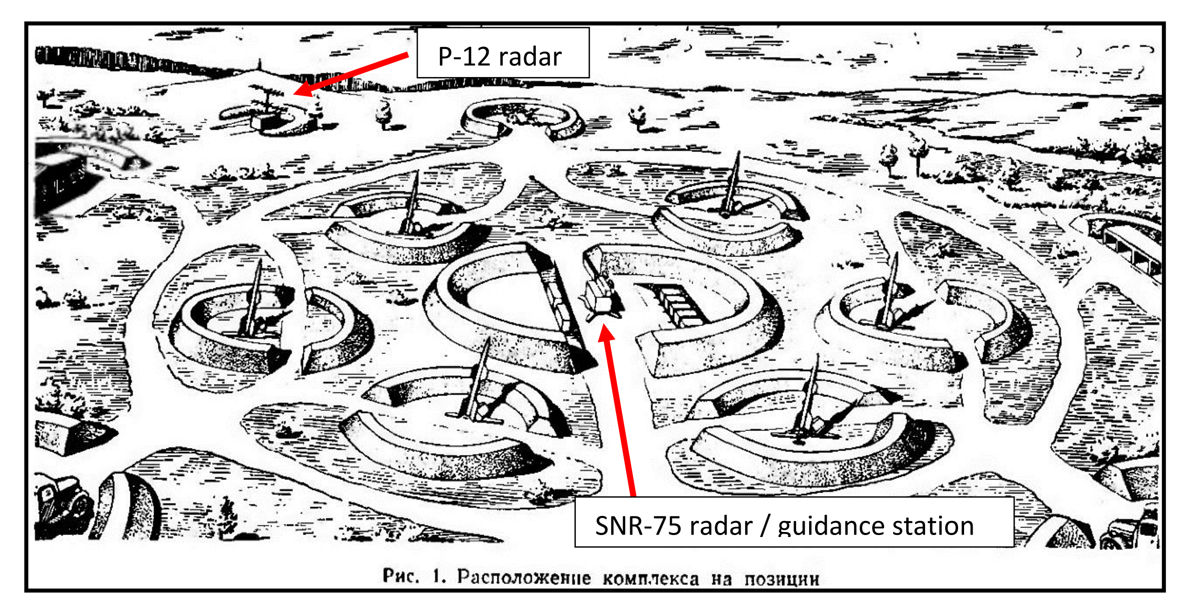


Рис. 1. Расположение комплекса на позиции

It was possible deploy the battery into the field but is calling because of this feature the Dvina or Volkhov mobile SAM would be an overstatement, the relocation time of Dvina was about 1.5 hour and 3.5 for the Volkhov. (Trained crew could do faster but still in hour scale even for Dvina.) This is why called “deployed” SAM, mobile SAMs are army SAM systems as 2K12 Krug or the 2K12 Kub. For army air defense was used only as a temporary solution until the 2K11 Krug replaced (in USSR) from mid ‘60s. In WPACT countries was not used the Volkhov on army level, until arrival or 2K11 Krug or 2K12 Kub (see in another chapter) they did not had army level missile air defense.

Below is a typical Dvina SAM site layout, the elements of the battery are labelled:

1. PAA cabin, RSNA-75M (Fan Song F) fire control radar.
2. UA fire control cabin (battery commander, guidance officer, manual target tracking, plot tables, launch system crew)
3. AA Instrument cabin (analog computer)
4. RMA power distribution cabin
5. 3 pcs. DES-100 cabins with 100kW diesel generators
6. 6 pcs. SM-63 PU launch rail
7. 6 pcs. PR-11 TZM missile transporter / loader
8. P-12 long range target acquisition (EW) radar

Another typical deployment type was using fortified battery posts for the cabins and vans of the Volkhov system. Of course the radars could not be sheltered but in case of attack the chance of survival of the crew was higher which has strong impact on morale.[14] On the image below is a hardened site in Hungary.

[14] In case of a non-nuclear war



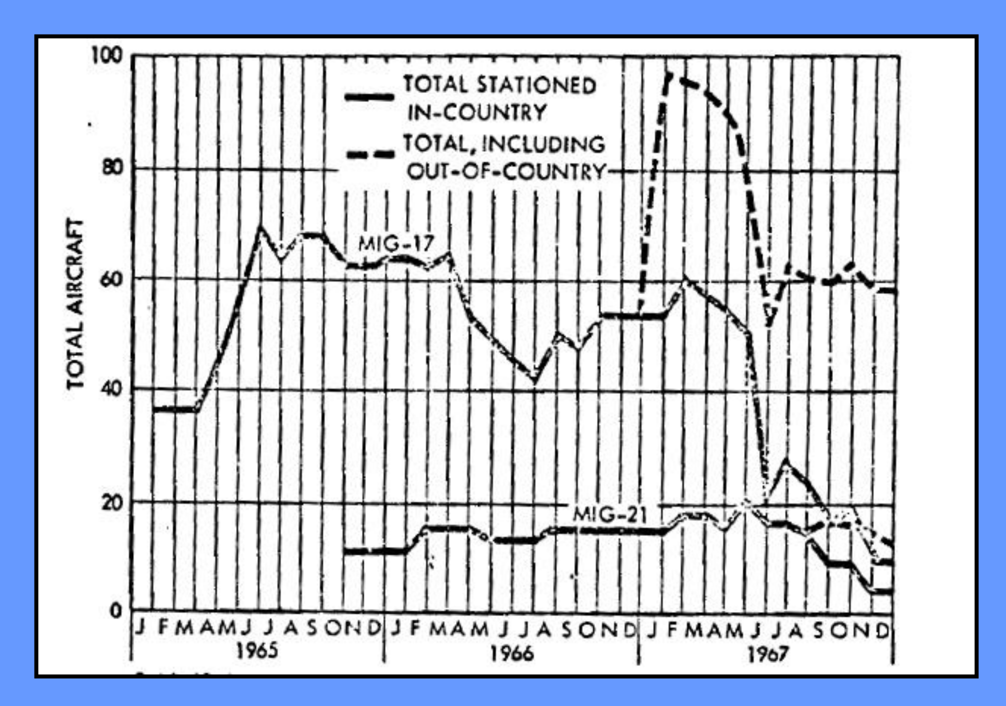
1. 5F24 integrated air defense system interface cabin and a 250 kg [550 lb] towed fire extinguisher
2. UV fire control cabin (battery commander, guidance officer, manual target tracking, plot tables, launch system crew)
3. AV instrument cabin (analog computer)
4. ZEF cabin (IFF system 'NRZ'), PRM-V cabin (spare part stock)
5. 2 pcs. 5E96 cabin (Each with two 100 kW diesel generator)
6. 1 pc. 5E96 cabin (With two 100kW diesel generator), RKU-V power distributor cabin (allowing the system to feed from the generators or from the national power grid)
7. PV cabin, RSN-75V3 (Fan Song E) fire control radar

The SA-75 Dvina was the first ever used SAM on battlefield which had very strong impact on developing the equipment of electronic warfare in the following decade or decades. Based on the acquired experience of Dvina in Vietnam leaded developing the first RWR systems and jamming equipment in USA. Of course the further development and upgrades of Dvina and Volkhov systems tried negates these counteractions of the USA, the good old battle between the "sword and the shield" continued now in the electronic warfare.

By judging only the hit rate of kill rate – see in a later chapter – it may seems missile air defense was not successful but it has to underline appearing on the battlefield Dvina induced serious countermeasures. It required new hardware to counter the new type of threat; different tactics had to be invented, etc. During the service of Dvina and Volhkov they were more successful than Soviet fighters in local wars but it has to be noted the fighter pilots mostly fought in inferior state and SAMs/AAAs got much stronger support then acquisition of fighters.

Vietnam acquired about 93 SA-75 Dvina batteries and 7 700 missiles between 1965 and 1972. For comparison **the whole Warsaw Pact** (Hungary, Poland, East Germany, Bulgaria, Romania and Czechoslovakia) acquired 96 SA-75 Dvina batteries and 11 training batteries between 1959 and 1962.

Comparing to this huge numbers only about 200 MiG-21 fighters (F-13 and PF) and about 300 MIG-17 were exported by USSR and China. From this qty. the MiG-17 was outdated even in early '60s it did not have any guided air to air missiles it had only guns for air combat. The available aircraft qty. are in the chart below, we can see losses had strong impact on available fighter quantity.



The price of a MiG-21F-13 was 3.5 million Rubles while a single Dvina battery cost was 9.5 million Rubles, a single V-750 missile cost was 217 thousand Rubles. Considering these basic figures only about SAMs Vietnam spent about one and half times more as on fighters. Besides the thousands of SAMs also thousands of AAA guns were bought – which caused most casualties for USA see in a later chapter – and of course tens of thousands tons of ammo for them. A single S-60 AAA gun cos was 178 thousand Rubles and the fire control radar of an S-60 battery the SON-9 radar cost was 402 thousand Rubles. (In WPACT a single S-60 AAA regiment had x4 SON-9 radars and x24 S-60 guns.)

The disparity between allocated resources to land based air defense and fighter units is obvious. Among the attachments are more documents about prices and quantities.

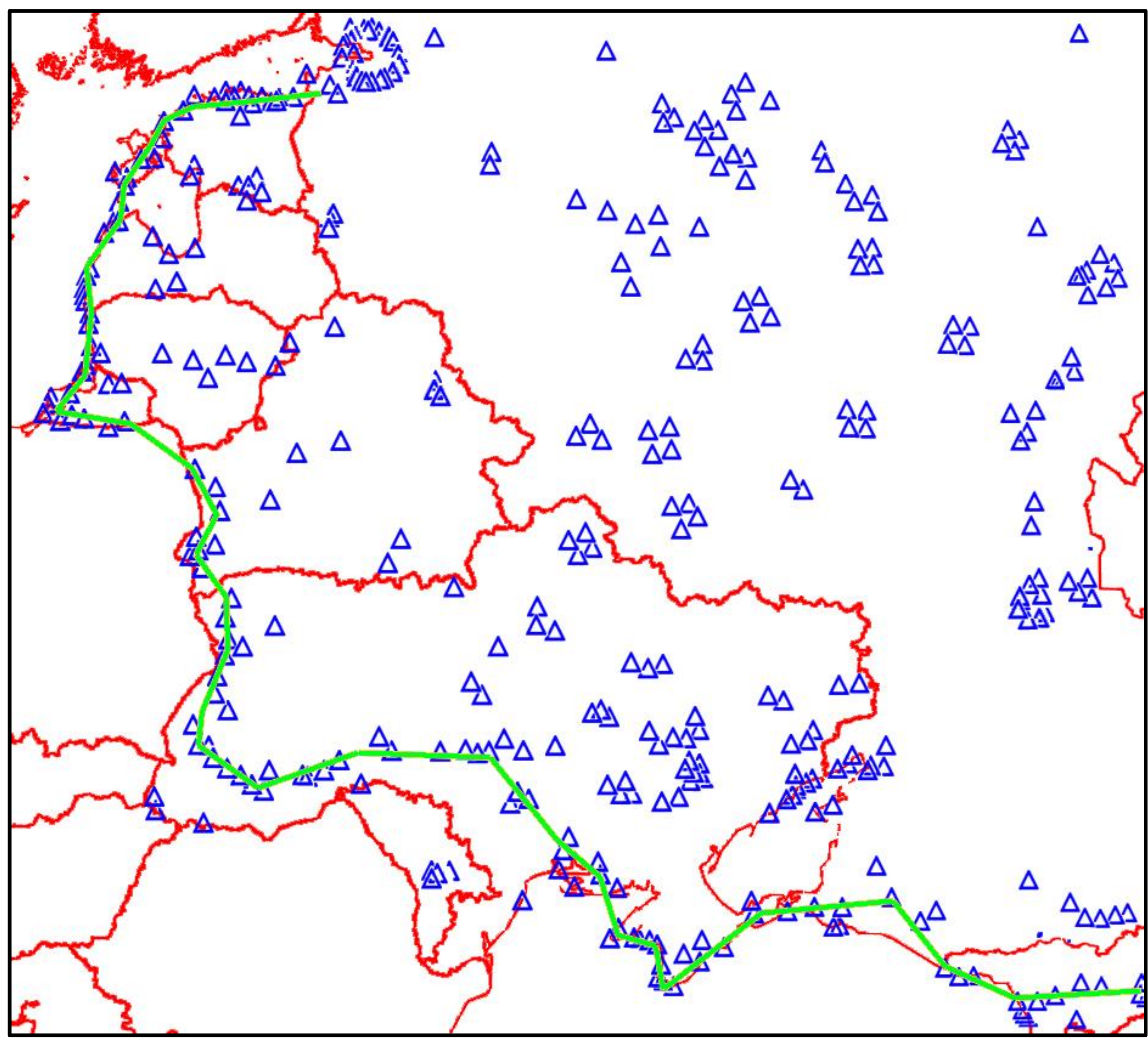
The SA-2 family was constantly improved during its lifetime and this was reflected in the types of targets used for practice shooting at Asuluk in the Soviet Union:

- From 1962 the target was an F-86 Sabre imitator.
- From 1968, high speed high altitude target was introduced (H>16 km, V> Mach2).
- From 1972, low altitude target was introduced (H <100m).
- From 1983, cruise missile target was introduced.
- From 1989, target imitating Stealth aircraft was introduced in Asuluk. [15]

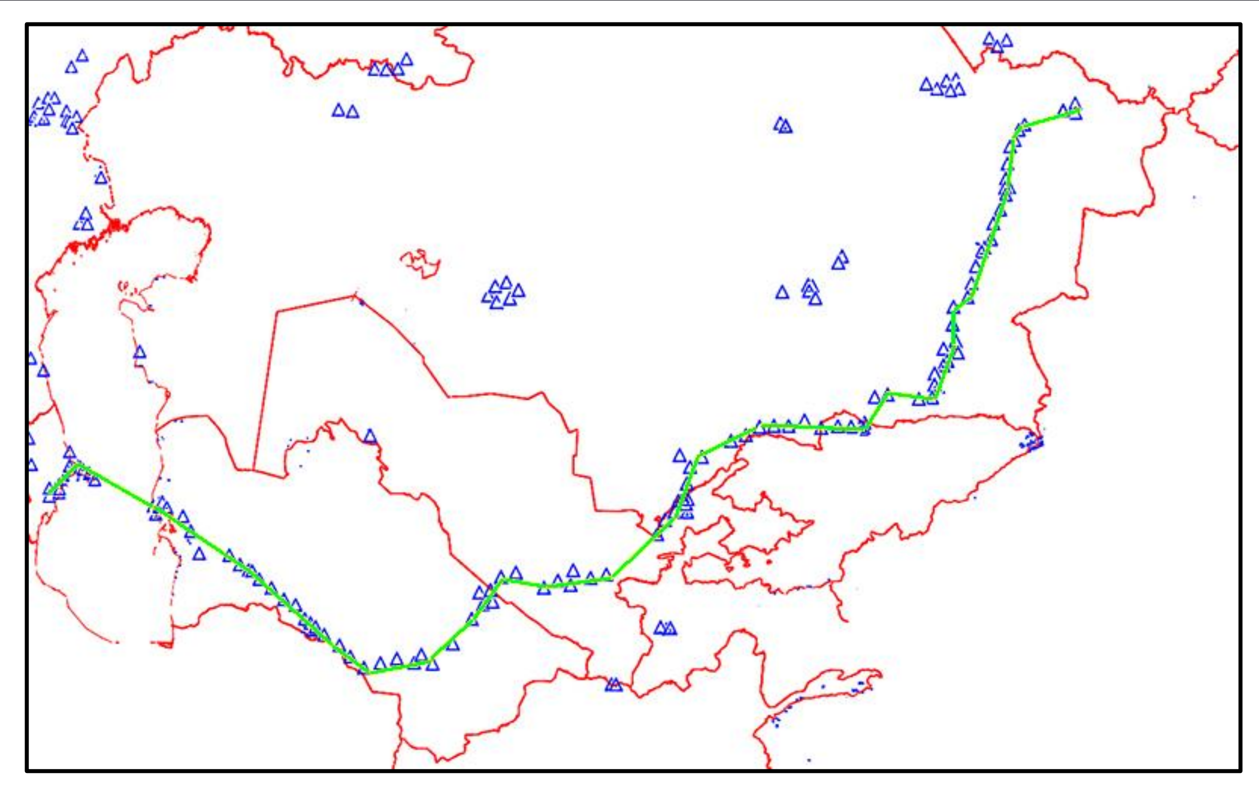
[15] *It should not extrapolate too far from this exercise because firing range environment is mostly very sterile and simplified comparing to real life situations. For example nobody ever launch and AGM-88 during training...*

In local wars the combat capability of both Dvina and Volkhov many times was restricted because the Soviet Union for a long time did not export automatized command posts or only in a very limited quantity. The SAM batteries searched target mostly without coordination using only their target acquisition radars, the best option was using the plot table method which is inadequate in complex tactical situations where lots of friendly and enemy aircraft can be is a small airspace. The Warsaw Pact members could get these automatized command posts but comparing to Soviet Union these elements of the integrated air defense system (IADS) appeared decade or decades later therefore they were one generation behind what the Soviets used. (See later in another chapter.)

The world longest contiguous SAM defense line was built up with using S-75M Volkhov, the border of the Soviet Union was protected by about 300 SAM batteries in 8500 km long border. The SAM defense line started at Leningrad (St. Petersburg) continued along the Polish, Slovakian, Hungarian and Romanian border, followed the coastline of Black Sea, through the Caucasus towards to Iranian, Afghan and Chinese border and ended at Mongolia. Most important Soviet cities also were protected by the SA-75/S-75M for example around Leningrad about 30 battery were deployed. In total Soviet Union deployed about 750 Volkhov batteries.



Above are the S-75 Volkhov SAM line along the border of USSR and the SAM rings around some Soviet cities in European part of the Soviet Union.



Above are the S-75 Volkhov SAM line along the border of USSR and the SAM rings around some Soviet cities in Asian part of the Soviet Union.

In my opinion this 8500 km long defensive line had no sense at all. When was completed the whole line the USA stopped the U-2 overflights after Soviets downed the U-2 near Sverdlovsk at 1st of May in 1960.

The MIG-25 entered into service at late ‘60s which was able to shoot down the U-2 without any special effort. If the U-2 had crossed the border it still would was required to launch MiG-25 to intercept the U-2 but such recon/spy flight would be pointless. It would mean too high risk for minimal benefits concerning to photographed area. (MiG-25 alert flights routinely were launched against SR-71 regardless it never violated airspace of WPACT or the USSR intentionally.) It was obvious USA never will use U-2 to perform overflights above USSR or WPACT because of the effective SAM defense and also because of political issues. So the U-2 as target disappeared but came a new the SR-71.

The later developed SR-71 never violated the airspace of WPACT or the USSR (political reasons) and against them none of the Dvina or Volkhov was usable as long as SR-71 performed simple noise jamming. Lots of Dvina missile were launched against SR-71 in other locations (Vietnam, Middle East, North Korea) and some Volkhov above Libya and none of them hit the Blackbird. (The Libyan Volkhov missiles were launched far outside of engagement zone.)

Against the hundreds of intercontinental bombers also was pointless the SAM line because it would be enough penetrate only at some locations then the attackers could spread above the huge airspace of the USSR. Moreover most of the line was simply ad bad locations because the intercontinental bombers of the SAC would arrive from polar region and not from east or south...

In case a nuclear war only some AGM-28s would be enough to punch a big gap into the SAM line because of the single target channel of the SA-75/S-75M and only 6 missiles were ready to launch. The rules of engagement dictated to launch 3 missiles against a single target so even in best case only two AGM-28s could be engaged was no time to reload. Considering the engagement zone seems to me impossible to attack two incoming AGM-28 if the launched with minimal time separation. Even just engaging two very high speed targets was impossible because of lack of automatization.

(In Vietnam crew many times violated the 3 missile engagement rule because of the different type of "mobile" usage, many times not the full battery relocated and deployed in the field.)

We can imagine the amount of resources which required building up and keeping operational the 300 SAM sites many times in the "middle of nowhere". Each site cost was about 11 million Rubles which in that time counted on 1:1 USD parity. For comparison USA and Canada disbanded the DEW[16] radar line in Polar Regions long before the Cold War ended.

The Dvina system mostly replaced with Volkhov from late '70s and early '80s in WPACT and after end of Cold War most of operators phased out Dvina (if they still had it) and also the Volkhov. Russia retired the last Volkhov battery in 1996 after deploying the S-300PM Volkhov-M6M (SA-20A) systems. After about four decades of service the career of SA-2 family in Russia ended.

Finally – as usual – here are some gallery and video links about the Dvina and Volkhov SAM family.

http://www.ausairpower.net/APA-SNR-75-Fan-Song.html
http://www.ausairpower.net/APA-S-75-Volkhov.html
http://www.ausairpower.net/APA-Rus-SAM-Site-Configs-A.html
https://www.youtube.com/watch?v=oQExlyBBoUo

[16] *https://en.wikipedia.org/wiki/Distant_Early_Warning_Line*